

CFD Validation of Synthetic Jets and Turbulent Separation Control: Synthetic Jet into Quiescent Air

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Motivations

- Assess the influence of turbulence modelling for synthetic jet simulation**
 - 2D laminar
 - 2D URANS
 - 3D LES
- Evaluate the cost of such computations**

Outlines

- Governing eqs. and SGS modelling**
- Numerical method**
- Numerical parameters**
- Results comparisons**

Governing Eqs. and SGS modelling for LES

- Compressible filtered Navier-Stokes Eqs.

- SGS modelling

- Selective Mixed Scale Model (SMSM) (Lenormand et al., AIAA J. 00)

- $$\mu_t = \bar{\rho} f_{\theta_0}(\theta) C_m \Delta \sqrt{0.5 S_{ij}(\tilde{u}) S_{ij}(\tilde{u})} \sqrt{K_c}$$

- $$f_{\theta_0}(\theta) = \begin{cases} 1 & \text{if } \theta > \theta_0 = 10^\circ \\ \tan^4(\frac{\theta}{2}) / \tan^4(\frac{\theta_0}{2}) & \text{otherwise} \end{cases}$$

Governing Eqs. and URANS modelling

- Compressible Navier-Stokes Eqs.
- Turbulent modelling: Spalart-Allmaras model

$$\frac{\partial \bar{\rho} \tilde{\nu}}{\partial t} + \frac{\partial (\bar{\rho} \tilde{u}_j \tilde{\nu})}{\partial x_j} = \underbrace{c_{b1} \tilde{S} \bar{\rho} \tilde{\nu}}_{Production} + \underbrace{\frac{1}{\sigma} \left[\frac{\partial}{\partial x_j} \left((\nu + \bar{\rho} \tilde{\nu}) \frac{\partial \tilde{\nu}}{\partial x_j} \right) + c_{b2} \frac{\partial \tilde{\nu}}{\partial x_j} \frac{\partial \bar{\rho} \tilde{\nu}}{\partial x_j} \right]}_{Diffusion} - \underbrace{\bar{\rho} c_{w1} f_w \left(\frac{\tilde{\nu}}{d} \right)^2}_{Destruction}$$

$$\mu_t = \bar{\rho} \tilde{\nu} f_{v1} = \bar{\rho} \nu_t$$

$$c_{b1} = 0.1355$$

$$c_{b2} = 0.622$$

$$c_{w1} = \frac{c_{b1}}{0.41^2} + 1.5 \times (1 + c_{b2})$$

Numerical method (1)

- **Finite volume method**
- **Multi-block curvilinear structured mesh**
- **Space discretization**
 - viscous fluxes: 2nd order centered scheme
 - Euler fluxes: 2nd order Hybrid upwind/centered discretization (adapted to low Mach number)
- **Time integration**
 - implicit: 2nd order bdf
 - approximate Newton
 - Euler fluxes: Jameson-Turkel (scalar)
 - viscous fluxes: Coackley
 - linear solver: LU-SGS

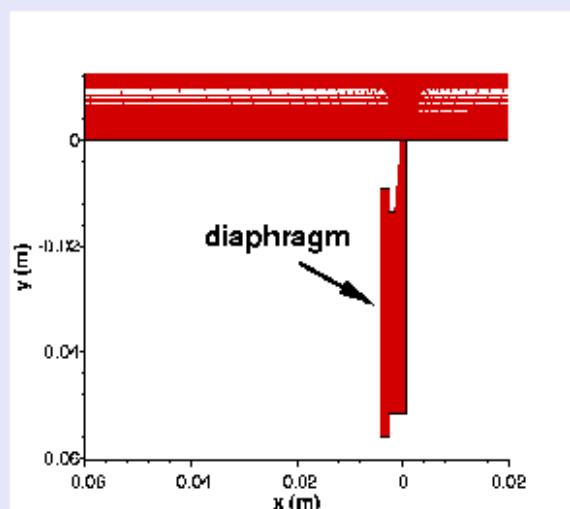
Numerical method (2)

Hybrid upwind/centered discretization (AIAA J., 2002)

$$F_{i+1/2} = \frac{\bar{u}_1}{2}(Q_L + Q_R) - \Phi \frac{|max(\bar{u}_1, c_1)|}{2}(Q_R - Q_L) + \frac{p_L + p_R}{2}$$

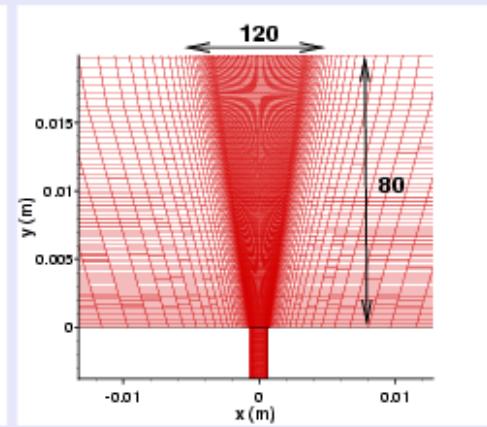
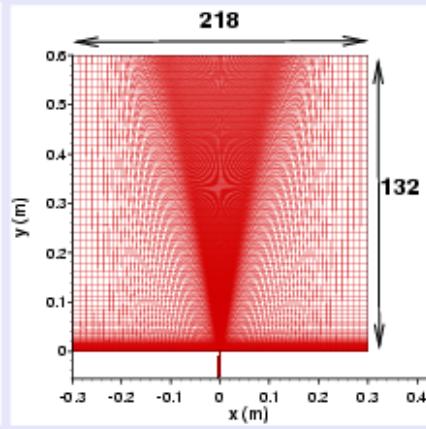
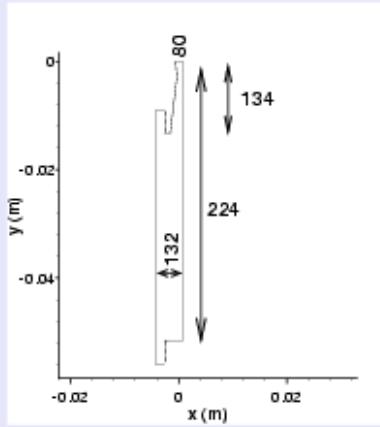
- based on simplified AUSM+(P) scheme
- L/R : 3rd order MUSCL interpolation
- $\bar{u}_1 = \frac{u_{1,L} + u_{1,R}}{2} - c_2(p_R - p_L)$
- Accuracy independent of M_∞
- $\Phi \rightarrow$ wiggle detector (numerical dissipation switch)

Diaphragm modelling



- The flow is simulated inside the cavity
- The diaphragm motion is modelled by an unsteady boundary condition
 - $V(y) = V_{exp} \sin(2 \times \pi \times 444.7 \times t) \quad \forall y$
 - V_{exp} = time derivative of the experimental measurement of the diaphragm
 - $V_{exp} = 0.5 \text{ m/s}$

Grid description



grid spacing at the exit of the cavity

- $\Delta y = 0.1\text{mm}$
- $\Delta x = 0.004\text{mm}$ at the wall

LES computation (3D grid)

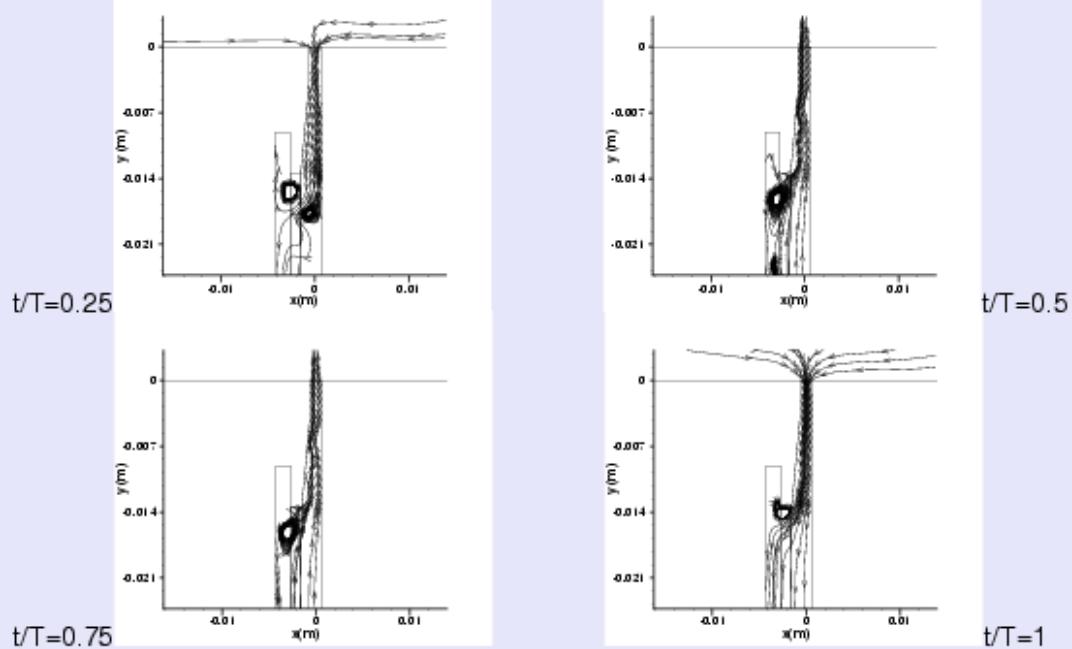
- $L_z = 1.3\text{mm} \approx \text{one channel diameter}, N_z=18$
- flow periodicity is assumed in the spanwise direction

Numerical parameters

- number of cells: 52000 (2D), 930000 (3D)**
- $\Delta t = 0.45\mu s \rightarrow 5000$ time steps/period
- Averaging procedure**
 - in time over: 50 periods (URANS), 140 periods (laminar), 17 periods (LES)
 - homogeneous spanwise direction for LES
- ≈ 5 CPU hours/ period for LES (1 proc. NEC SX5, ≈ 4 Gflop)

Results (1)

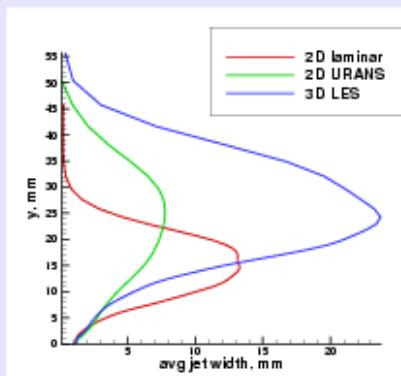
Unsteady flow features inside the cavity (2D laminar)



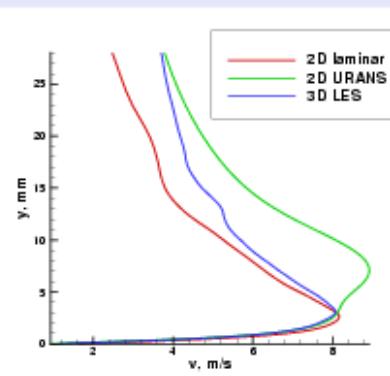
Vortices are mostly controlled by the geometry: → small influence of turbulence modelling

Results (2)

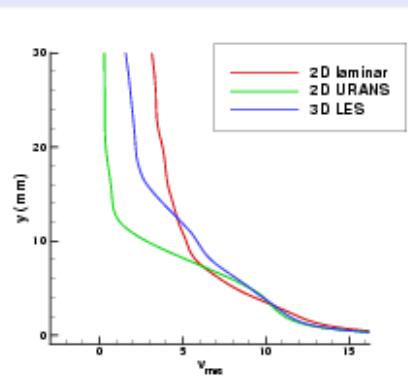
Influence of turbulence modelling



Mean jet width of the jet



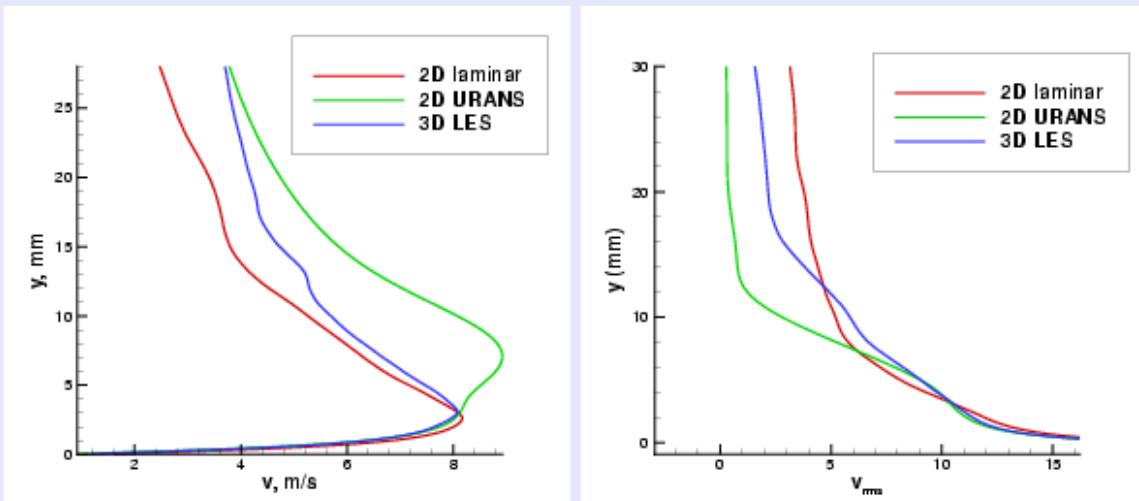
Mean vertical velocity



RMS vertical velocity

Results (3)

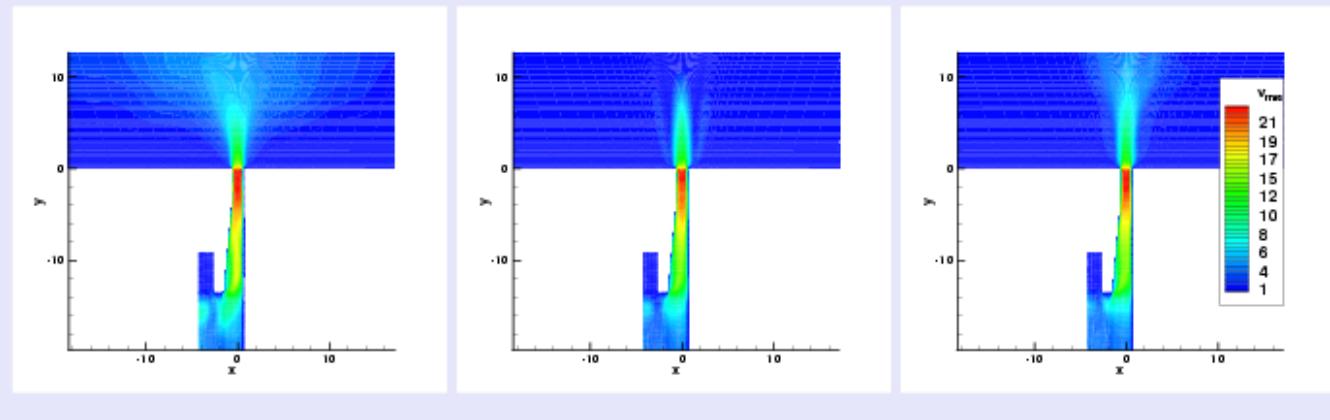
Influence of turbulence modelling



Mean and RMS vertical velocity

Results (4)

RMS vertical velocity component



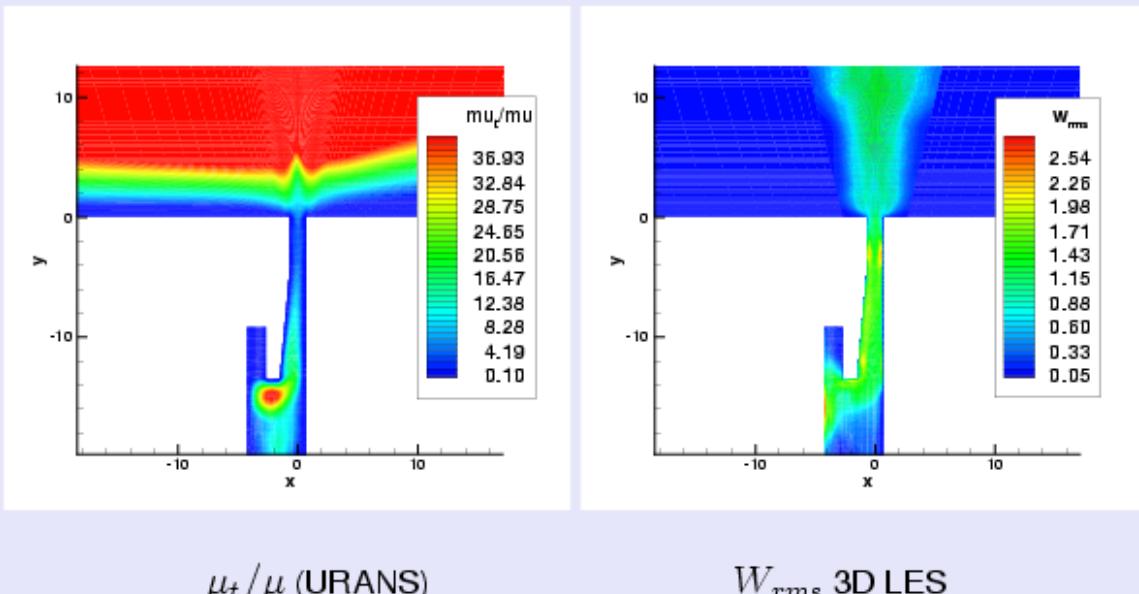
2D laminar

2D URANS

3D LES

Results (5)

RMS vertical velocity component



Conclusions and perspectives

Small influence of turbulence modelling inside the cavity

- the flow is almost laminar
- the flow separation is fixed by the geometry
- spanwise velocity fluctuation are low in the LES simulation

Larger influence of turbulence modelling in the jet

Perspectives

- Real 3D geometry
- improve time integration method